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M DWARFS FROM *HUBBLE SPACE TELESCOPE* STAR COUNTS. V. THE *I*-BAND LUMINOSITY FUNCTION[1]

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ABSTRACT

We derive the disk *I*-band luminosity function from the Zheng et al. sample of $\sim$1400 disk M dwarfs observed with the *Hubble Space Telescope*. We adopt a Galactic-height–dependent color-magnitude relation to account for the metallicity gradient above the Galactic plane. The resultant *I*-band luminosity function peaks at $M_I \sim 9.5$ and drops sharply toward $M_I \sim 10.5$.

Subject heading: stars: late-type — stars: low-mass, brown dwarfs — stars: luminosity function, mass function — stars: statistics — surveys

1. INTRODUCTION

The stellar luminosity function (LF) measures the number density of stars as a function of luminosity. It is traditionally expressed in the *V* band. However, sometimes it is more convenient to use the *I*-band LF for planning and modeling observations. Here we present the *I*-band LF of disk M dwarfs from *Hubble Space Telescope* (*HST*) star counts.

Zheng et al. (2001) studied a sample of about 1400 disk M dwarfs found in 148 fields observed with the Wide Field Camera 2 on the *HST* and 162 fields observed with the pre-repair Planetary Camera 1. The *V*-band LF and the Galactic disk parameters were derived simultaneously using the method of maximum likelihood. If the luminosity of M dwarfs depended only on their color, as is the case for example for the solar neighborhood color-magnitude relation (CMR) determined by Reid (1991), the conversion from the *V*-band LF to the *I*-band LF would be straightforward. However, since many stars in their sample lie far from the Galactic plane, Zheng et al. (2001) introduced a more realistic CMR [CMR (2) in that paper], which makes a first-order correction for the metallicity effect: the luminosity then depends not only on the color but also on the height, *z*, above the Galactic plane. With this more complex CMR, the transformation from the *V*-band LF to the *I*-band LF is not trivial.

In this paper we apply the method of maximum likelihood to the same set of *HST* observations as in Zheng et al. (2001) and incorporate the Galactic-height–dependent CMR to derive the *I*-band LF of M dwarfs. This direct method avoids the uncertainty and the difficulty in the transformation from the *V*-band LF to the *I*-band LF. For details on the observations, the CMR, and the maximum likelihood method, we refer readers to Zheng et al. (2001) and references therein. In § 2 we present our results after a brief description of models.

2. MODELS AND RESULTS

The LF of disk M dwarfs is a function of the Galactic position (R, z). We parameterize it as the product of a vector of 12 absolute *I*-magnitude bins and a Galactic density law,

$$\Phi(i, z, R) = \Phi_i \nu(z) \exp\left(-\frac{R - R_0}{H}\right), \quad (1)$$

where Φ_i is the solar neighborhood LF for the *i*th magnitude bin, $R_0 = 8$ kpc is the Galactocentric distance of the Sun, and H is the scale length of the disk. The vertical density profile $\nu(z)$ is assumed to have either a sech^2 form,

$$\nu_s(z) = (1 - \beta)\mathrm{sech}^2\frac{z}{h_1} + \beta \exp\left(-\frac{|z|}{h_2}\right), \quad (2)$$

or a double-exponential form,

$$\nu_e(z) = (1 - \beta) \exp\left(-\frac{|z|}{h_1}\right) + \beta \exp\left(-\frac{|z|}{h_2}\right). \quad (3)$$

The magnitude bins are centered at $M_I = 6.5$, 7.0, 7.5, 8.0, 8.5, 9.0, 9.5, 10.0, 10.5, 11.0, 12.0, and 13.5. The size of each bin is 0.5 mag except the last two (1.5 mag). Given a choice of disk scale length H, the local LF, Φ_i, and the three disk profile parameters (h_1, h_2, β) are found by maximizing the likelihood. The scale length is determined by finding the maximum in the maximized likelihoods of an ensemble of solutions using different values of H.

As in Zheng et al. (2001), we select stars below $z = 2400$ pc. The absolute I magnitude of stars should satisfy $6.25 < M_I < 14.25$. The bright boundary is set to prevent contamination by spheroid giants. When translated into color, the boundary we use here is slightly bluer than that in Zheng et al. (2001), but it is still acceptable since our results show virtually no change if we move the boundary to a higher absolute I magnitude. Altogether, 1403 stars satisfy our selection criteria, and they constitute our sample. This sample has 30 more stars than the one used by Zheng et al. (2001), which results primarily from the small difference in the blue boundary.

We solve for the LF and disk profile parameters by maximizing the likelihood and find that the resultant disk profile parameters, for either the sech^2 model or the double-exponential model, are almost identical to those derived in

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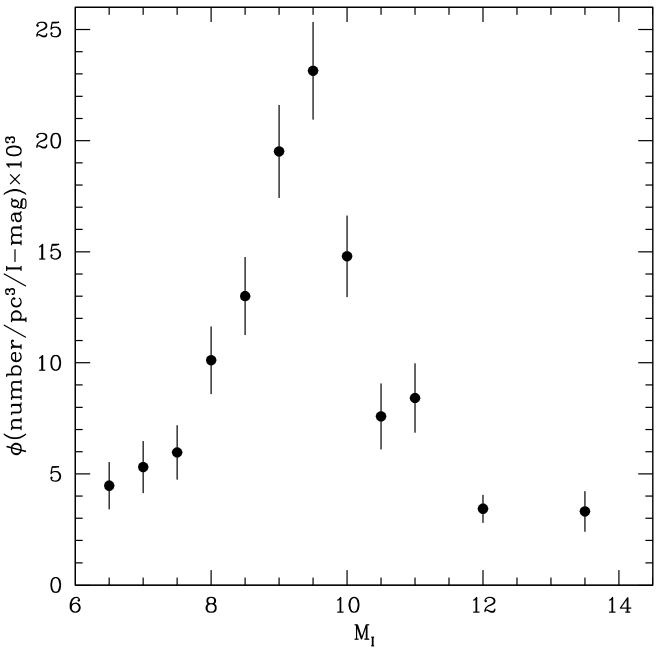

FIG. 1.—*I*-band luminosity function based on 1403 M dwarfs observed with *HST*.

Zheng et al. (2001). This consistency of the results implies that the disk profile derived from the maximum likelihood method is robust. We therefore decide to fix the disk parameters at the values in Zheng et al. (2001), namely, $h_1 = 270$ (156) pc, $h_2 =$ 440 (439) pc, $\beta = 56.5\%$ (38.1%), and $H = 2.75$ kpc for the sech^2 (double-exponential) model.

Similar to the case in *V* band, because of the lack of local stars in the sample, the best-fit LF for the sech^2 model and that for the double-exponential model have nearly the same shape but differ from each other in normalization, and the normalization difference is compensated by the vertical density profile. We adopt a linear combination of the LFs of these two models as our final result, with the same combination coefficient derived by Zheng et al. (2001) by matching the local normalization to the well-established luminous end of the solar neighborhood M-dwarf *V*-band LF.

The *I*-band LF from our analysis is listed in Table 1 and shown in Figure 1. As expected, the overall shape of the *I*-band LF, with a peak at $M_I \sim 9.5$ and a sharp drop toward $M_I \sim 10.5$, mimics the *V*-band LF in Zheng et al. (2001).

TABLE 1

THE *I*-BAND LUMINOSITY FUNCTION

M_I (mag)	ϕ (10^{-3} pc^{-3} *I*-mag^{-1})
6.5	4.5 ± 1.1
7.0	5.3 ± 1.2
7.5	6.0 ± 1.2
8.0	10.1 ± 1.5
8.5	13.0 ± 1.8
9.0	19.5 ± 2.1
9.5	23.1 ± 2.2
10.0	14.8 ± 1.8
10.5	7.6 ± 1.5
11.0	8.4 ± 1.6
12.0	3.4 ± 0.6
13.5	3.3 ± 0.9

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